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Applying the analytic technique, two antenna designs were found for which the radiation Q was below the limit determined by Chu for electrically small antennas. The simplest design is a turnstile antenna comprised of two perpendicularly oriented collocated electric dipoles that are phased to support circular polarization, for which the radiation Q is slightly less than a single electric dipole. The most intriguing antenna design consists of four spatially collocated equal power dipoles, a magnetic and electric dipole moment pair oriented along the x-axis, with the dipole pairs driven /2 out of phase to support circular polarization. For this source the analytically predicted radiation Q is zero independently of the relative electrical size ka of the antenna, where a is the radius of the smallest virtual sphere that circumscribes the antenna and k is the wave-number of radiation.

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Final Report: No. F49620-96-1-0353
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By: Dr. Craig A. Grimes, The University of Kentucky

Under the scope of program auspices the following milestones were achieved.

1. The first and only published analytic technique that correctly calculates the radiation Q of a general radiation field was developed [1,2].

2. Applying the analytic technique, two antenna designs were found for which the radiation Q was below the limit determined by Chu for electrically small antennas.

The simplest design is a turnstile antenna comprised of two perpendicularly oriented collocated electric dipoles that are phased to support circular polarization, for which the radiation Q is slightly less than a single electric dipole.

The most intriguing antenna design consists of four spatially collocated equal power dipoles; a magnetic and electric dipole moment pair oriented along the x-axis, and a magnetic-electric dipole moment pair oriented along the y-axis, with the dipole-pairs driven $\pi/2$ out of phase to support circular polarization. For this source the analytically predicted radiation Q is zero independently of the relative electrical size $ka$ of the antenna, where $a$ is the radius of the smallest virtual sphere that circumscribes the antenna and $k$ is the wave-number of radiation equal to $2\pi/\lambda$.

3. Numerical [3-5] and experimental [4,5] works have shown that the radiation Qs of the two different, multi-element antenna designs are a function of the relative phasing between the radiating elements.

4. The 'zero-Q' antenna has been experimentally and numerically characterized [5]. Experimentally, for the 'zero-Q' antenna of relative electrical size $ka = 0.39$, the measured Q is a factor of approximately three below the so-called Chu limit. Numerical simulations, with which we were able to characterize the antenna over a broader frequency range than possible with our experimental measurements, indicate that at $ka = 0.23$ the antenna Q is a factor of 20 below the Chu limit, and demonstrates wide-band operation indicative of self-tuning as discussed in [A]. Furthermore, while the energy field phasing required for low Q emission can be readily obtained in transmission, for reception the phasing for low Q operation is unlikely to be met by an incident wave, hence the antenna should operate as a non-reciprocal device [A].

[A] D.M. Grimes and C.A. Grimes, "Bandwidth and Q of Antennas Radiating TE and TM Modes," IEEE Transactions on Electromagnetic Compatibility, vol. 37, pp 217-226, 1995.

5. A total of 13 referred journal publications, 1 patent, and 8 conference proceedings acknowledged AFOSR support.

**Journal Publications Acknowledging AFOSR Support**


[1] D.M. Grimes, C.A. Grimes, Radiation Q of Dipole Generated Fields, Radio Science, vol. 34, No. 2, pp. 281-296, 1999.

[2] D. M. Grimes, C. A. Grimes, Minimum Q of Electrically Small Antennas: A Critical Review, in press Microwave and Optical Letters, December 20, 2000.

[3] G. Liu, K.G. Ong, C.A. Grimes, D. M. Grimes, Comparison of Time and Frequency Domain Numerical Modeling of Outbound And Local Power From Two Perpendicularly Oriented, Electrically Small TM Dipoles, Int. Journal of Numerical Modeling, vol. 12, pp. 229-241, 1999.

[4] Craig A. Grimes, Gang Liu, Faton Tefiku, Dale M. Grimes, Time Domain Measurement of Antenna Q, Microwave and Optical Technology Letters, vol. 25, No. 2, pp. 95-101, 2000.

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[12] K.G. Ong, C.A. Grimes, A Method For Quantifying The Higher-Order Modes Radiated By An Arbitrarily Shaped Antenna. Microwave and Optical Technology Lett., vol. 24, pp. 20-24, 2000.

[13] G. Liu, C.A. Grimes, A Quasi-static FDTD Source Model for Coaxially Driven Monopole Antennas. Journal of Microwave and Optical Letters, vol. 26, pp. 30-34, July 5 issue, 2000.

**Patents Acknowledging AFOSR Support**

[1] C.A. Grimes, D. M. Grimes, F. Tefiku, G. Liu. Electrically-small Low Q Radiation Source/Antenna and Associated Methods of Producing such a Source and Transmitting an EM Signal with such a Source. U.S. Patent Pending, filed September 9, 1999.

**Conference Proceedings Acknowledging AFOSR Support**

[1] C.A. Grimes, D.M. Grimes, The Poynting Theorems and The Potential for Electrically Small Antennas. Proceedings IEEE Aerospace Conference, pp. 161-176, 1997.

[2] Gang Liu, Craig A. Grimes, Keat Ghee Ong, and James E. Lumpp, Dale M. Grimes, Time and Frequency Domain Modeling of Outbound and Standing Power from Perpendicularly Oriented, Electrically Small TM Dipoles, Proceedings IEEE Aerospace Conference, Volume 3, pp. 264-272, 1998.

[3] Craig A. Grimes, Dale M. Grimes, The Q of Dipole, TM Radiation Fields, Proceedings IEEE Aerospace Conference, Volume 3, pp. 255-264, 1998.

[4] Craig A. Grimes, James L. Horn, Rony Shahidain, and Faton Tefiku, Control of Antenna Input Impedance Through Cancellation of Near Field Standing Energy, Proceedings IEEE Aerospace Conference, Volume 3, pp. 273-282, 1998.

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